Study of Caliche Soil as a Filter Medium for Treatment and Disposal of Wastewater

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Introduction:

Through a grant from the Texas On-Site Wastewater Treatment Research Council, the senior author has initiated a project to search the literature relative to caliche materials as a medium for treatment and disposal of wastewater. It was hypothesized before undertaking this effort that there would be a dearth of published and unpublished information on this subject. The project was initiated November 1, 2000 and is to be completed by March 31, 2001. Specifically, the goals of the project were to:

- Provide a working definition of "caliche" in relation to treatment of wastewater.
- Perform a comprehensive literature review on the effectiveness of caliche soils as a bioremediation filter media in the treatment and disposal of wastes.
- Develop a bibliography of all references on the subject with a brief summary or abstract of contents.
- Summarize findings on the effectiveness of caliche to treat and dispose of wastewater from subsurface disposal systems based on what has already been researched.
- Develop recommendations for future research that would address issues identified above.

How was the Literature Review Conducted?

The literature review was conducted initially by using the traditional searches with library computer search engines (Table 1). There are other search engines available besides the ones that were used; however, each search engine uses one of the few main database sources for abstracts. Two engines that use the same database source reap the same abstracts. For each of the keyword combinations, we used one search engine per database source. There are a few of the database sources that we have not been able to access up to this date. (for example NASA and Usgov). However, we believe those searched to date have reaped the major responses. Listed below in Table 1 are the search engines used and the source of the database.

Search Engine	Source of Database
GeoRef	SilverPlatter and Web Spirs.
Agricola	National Agricultural Library's (NAL).
Web of Science	Institute for Science Information (ISI).
First Search	Article First, UnionLists and Paper First.
CAB Abstracts	Ovid.
Water Resources Abstracts	Cambridge Scientific Abstracts (CSA).
Applied Science & Tech Abstracts	Wilson Web.
Compendex	Engineering Information (Ei).

Listed below are the keyword combinations used within each search engine query to narrow citations most appropriate for this literature search: pH + filter field, pH + septic systems, pH + effluents, pH + sewage, carbonate + filter field, carbonate + septic systems, carbonate + effluent, carbonate + sewage, petrocalcic + filter field, petrocalcic + septic systems, petrocalcic + effluent, petrocalcic + sewage, calcium carbonate + filter field, calcium carbonate + septic system, calcium carbonate + effluent, calcium carbonate + sewage, caliche + filter field, caliche + septic systems, caliche + effluent, caliche + sewage, , wastewater + pH, wastewater + calcareous, wastewater + calcium carbonate, wastewater, wastewater + petrocalcic, wastewater + caliche, and wastewater + limestone.

Because the results from the traditional literature were limited, an overall search through non-scientific search engines was conducted. The search engines were Yahoo, HotBot, Alta Vista, Excite and Dogpile. There was no usable information gathered using these sources. Most of the information found was either too general or was advertisements for consulting companies.

In addition to literature searches, 102 letters were sent to professionals in the western states working for state and federal government agencies. The professionals included pedologists, engineers, chemists and geologists. Letters were sent to TNRCC employees in the counties of Texas that contain caliche soils. These responses should yield additional information on gray literature (that not found in the traditional literature citations). These letters were submitted at the end of December 2000, and insufficient time has elapsed for fruitful response from these communications.

What is Caliche?

The literature search was not productive in elucidating information about caliche concepts. As noted in last year's presentation to the Texas On-Site Wastewater Treatment Research Council's Conference (Wilding, et al.,1999), the term "caliche" is a very broad, ambiguous and sometimes misleading term. It has both geological and pedological contexts and stems from the Latin root *cal* meaning lime. Because of the common usage of the term caliche in engineering and wastewater practicing professional circles of Texas, the term caliche will be retained but its working definition will be restricted, and its usage limited to a pedological context.

The working definition of caliche is "*a pedogenically altered limy material that contains more than 40% calcium carbonate equivalent and has sufficient accumulation of pedogenic carbonates to meet the minimum requirements of a calcic or petrocalcic horizon*" as defined in Soil Taxonomy (Soil Survey Staff, 1998). These materials may be either indurated (petrocalcic) or non-indurated (calcic); they have variable texture, morphology, thickness, and origin; however, they are differentiated from soft and hard limestones, or sediments derived therefrom, by sufficient weathering to form accumulations of pedogenic carbonates equivalent to at least 5% by volume identifiable forms (e.g. carbonate filaments, threads, soft masses, hard nodules, coatings, pedants, etc.). This is important because of enhanced organic matter and soil structure, which influence biotic activity, porosity and pathways of water movement.

The above definition clearly restricts caliche *to weathered soil materials*. This definition would exclude, for example, unweathered marls, chalks, soft limestones, hard limestones, and highly calcareous recent alluvial deposits. While some of these materials may be used as on-site wastewater treatment media, they are geologic materials and not caliche. This distinction is important because pedogenic materials contain higher levels of organic matter and porosity that directly influence the bioremediation quality of caliche materials. Higher organic matter contents favor higher microbial activity and oxidation rates of organic compounds under well drained conditions, and higher denitrification of nitrates under wet, anaerobic soil conditions. Enhanced porosity resulting from soil weathering increases microporosity and water retention. On the other hand, the formation of soil structure, biopores, and other types of macropores (fissures, cavities or fractures) may enhance flux of water and waste effluents through the soil without sufficient residence time for adequate bioremediation. Such effects could lead to increased losses of nitrates, phosphates, and other contaminants to ground waters, and thus decreased bioremediation quality of the caliche material. Lastly, pedogenic weathering of caliche materials can effectively translocate carbonates to lower soil layers and plug macropores such as bedrock joint planes, fissures and fractures so that these conduits are less effective in transmitting pollutants into and through water recharge vadose zones.

Where Can Caliche Be Found?

Regional distribution of caliche is mostly west of the 97th degree meridian in the U.S. (Machette, 1985, Fig. 1). However, this small-scale map likely omits large areas in south Texas and sections of the High Plains where caliche soils are known to occur.

Geological Inferences: Geologic/physiographic regions in Texas favorable for the formation of caliche soils are given in Figure 2 (Bureau of Economic Geology, 1992 and Ferguson, 1986). The units shown on this state-wide map are chiefly drawn along geologic boundaries, although certain physiographic regions are also delimited without regard for geologic age and rock types contained within these regions (for example, the mountainous reaches of Trans Pecos Texas). Virtually the entire extent of presumed geologic/geographic environments conducive to caliche soils in Texas lies west of the 98th Meridian (which roughly coincides with the 30-inch isohyet). But included within the various map units are certain areas that do not typically include extensive caliche soils; for example, most of the Edwards Plateau is noted for its thin, rocky soils, and much of the mountainous terrain of Trans Pecos comprises rocky uplands without widespread caliche soils. Yet for both regions, local areas may be expected to exhibit caliche soils. Notable areas having widespread caliche soils include the Hill Country carbonate-rock terrain, the Reynosa Plateau of South Texas, and alluvial plains occurring in various geologic/geographic provinces-ranging from the extensive gravel plains off the edge of the Caprock Escarpment; Uvalde Gravels and related alluvial plains off the southern edge of the Balcones Escarpment; and the bolsons of the Trans Pecos Basin and Range Province. The Caprock Caliche, which makes up part of the Ogallala Formation, underlies the vast reaches of the High Plains; yet caliche soils may generally be restricted to local playas and stream incisions, owing to widespread cover by aeolian sand sheets. Because of scale of base maps used for this illustration, much allowance must be made for inclusions of materials that vary from the general descriptions of the various units.

Soil Survey Inferences: *A* more comprehensive assessment of the distribution of caliche soil in Texas is illustrated in Figure 3. This information is based on detailed soil surveys (SURGO database) which has correlated acres of caliche soils. This database is available for most of the counties in Texas; where unavailable estimates of probable caliche soils are made from nearby counties. An asterisk is placed in those counties where such estimates were made. The database from SURGO suggests that 14 million acres (or about 8.4% of the State) are caliche soils. This is a conservative figure. When one considers all counties in the State (those with known and estimated caliche percentages), then the value will likely exceed 17 million acres, or over 10% of the State. This emphasizes the importance of caliche as a soil resource for on-site wastewater systems in Texas.

In general, there is a close relationship between the generalized geologic bedrock/physiographic regions in Texas with favorable conditions for caliche soils (Fig. 2) and actual percentages of counties with carbonatic (caliche) soil materials (Fig. 3). For example, many counties of the Hill Country, Lampasas Cut Plain, Alluvial Plains off Balcones Escarpment, and selected counties/or sectors thereof, in Southern Plateau Edge, Edwards Plateau and West Texas Bolsons have over 50% of the total area composed of caliche. It is noteworthy that incongruities also occur between the bedrock/physiographic map and soil databases, especially for the Rio Grande/Nueces Plain and Reynosa Plateau. Here soil surveys suggest either no caliche soils or percentages less than 10%. The reason for these disparities is not fully known but may represent in some cases caliche materials in soils that are below the depths considered for carbonatic mineralogy. In other cases, it may be due to soils that are developed from strongly calcareous materials but with insufficient carbonate contents to be carbonatic in mineralogy according to Soil Taxonomy (at least 40% calcium carbonate equivalent). In these cases areas of soil conditions that are *caliche-like* may be underestimated from soil maps.

What are the Properties and Attributes of Caliche?

Databases Available: No attempt is made in this paper to identify comprehensively all of the attributes of soils with calcic and petrocalcic horizons that meet our working definition of caliche, but readers are referred to the extensive data base available for soils of Texas and other regions of the U.S. which are on line (http://www.statlab.iastate.edu/soils/soil/div/). These databases give physical, chemical, mineralogical, and biological attributes for over 10,000 pedons including pedon descriptions, soil interpretations, and engineering behavior. Suffice to say, this data base can be used as a critical source of information to obtain laboratory and field attributes for soil series that have calcic and petrocalcic horizons above 40% calcium carbonate equivalent.

Examples of soils that fit the above concept of caliche in Texas have been published for the Edwards Plateau and the Grande Prairie by Rabenhorst and Wilding (1986a,b), West et al (1988), West et al (1989a,b), Woodruff, et al (1992), Wilding and Woodruff (1993) and Wilding et al (1997). Selected chemical, mineralogical and physical attributes are considered below.

Chemical Attributes: While attributes of carbonatic soils containing calcic and petrocalcic horizons are quite variable, several common relationships exist. These soils have high calcium carbonate equivalents (40-90%). The carbonate minerals are dominantly calcite and dolomite. Caliche soils have alkaline soil reactions buffered in pH ranges from 7.5-8.3. This means that many elements are sparingly soluble for plant uptake or subsequent soil leaching. In spite of commonly held misconceptions, the organic carbon (OC) contents of surface horizons are much higher than their colors would indicate (1-5%) and subsoils commonly contain 0.5-2% OC. In spite of their high carbonate content, these soils have moderately high to high chemical sorbtivity with cation exchange capacities of 10-30 meq/100g soil for surface horizons and 3-20 meq/100g soil for subsoils. This reflects the presence of OC and active clay minerals, both of which have high chemical sorption potential. Nutrient deficiencies in caliche materials are quite common, especially for plant available N, P, Fe, and trace elements.

Mineralogical Attributes: The mineralogy of non-carbonate clays in caliche is predominantly smectite, regular and random mixed-layer assemblages (smectite-mica or vermiculite-mica), mica, quartz, and lesser amounts of kaolinite. Hence, the fine-earth component of these soils has appreciable shrink-swell potential in spite of their high carbonate content. The sand and silt fractions of caliche materials are primarily calcite and dolomite with secondary amounts of relatively unweathered and stable quartz, feldspars, pyroxenes, amphiboles, and heavy minerals. Hence, most of the coarse separates of caliche materials do not weather rapidly to yield plant-available nutrients, other than Ca and Mg. This is due in part to the highly buffered pH of these materials, which retards chemical weathering. It is due also to the fact that most of the non-carbonate detrital grains in limestone are stable minerals--the more weatherable forms have been weathered prior to depositional cycles associated with the genesis of the limestone bedrocks.

Physical Attributes: Many caliche soils have loamy to clayey textures and are skeletal which means they contain more than 35% by volume of gravels, rocks, and stones; however, non-skeletal analogues also occur, especially in alluvial valleys. *Para* gravels, rocks and stones, which are weak to moderately cemented, are common in soils developed from soft limestones, marls, or alluvial deposits derived therefrom. These para fragments wet via macro pores in the rock fabric. This enhances the water retention potential for caliche materials and makes them less droughty than one might predict, and enhances bioremediation quality.

Soil drainage, soil thickness, water retention, and infiltration rates are highly variable among caliche materials--they are soil and site specific. They vary with nature of parent materials (origin and consolidation), vegetative cover, landform position, landform geometry, microtopography, slope gradient, stoniness, surface crusting, soil degradation, biological activity, and intensity of soil development processes.

A case example of soils with caliche is the stepped landforms of the Hill Country of central Texas (Woodruff, et al., 1992 and Wilding et al., 1997). The bedrock is interbedded hard and soft Glen Rose Limestone. In these stepped landscapes, at lateral intervals of 30 to 60 ft, the soils exhibit remarkable and unique spatial diversity corresponding to steep "risers" and gently sloping "treads". For example, they have the following short-range attributes: (1) soil thickness that varies from less than 1 foot to over 5 feet; (2) slope gradients that range from 1 to 40%; (3) infiltration rates that vary from less than 1 to over 6 inches/hr; (4) average cumulative runoff which ranges from 1% of the annual rainfall to 28%; (5) erosion rates that range from nil to 1.5 tons/A/yr; (6) water retentions that range from 0.3 to 7 inches; and (7) stone contents that range from 25 to 70%. In general, from risers to treads the trends are as follows: decreasing soil thickness, decreasing biological activity, decreasing soil permeability, decreasing water storage, increasing runoff and sediment transport, increasing hydrological curve numbers (less infiltration and higher runoff from storm events) and decreasing remediation quality.

Hydrological Attributes: Hydrology of caliche soils is critical to their functioning as filter field media for wastewater treatment systems. Unfortunately, little is known about the effective pathways of water transport, mean residence time of fluids in transport, density flux distributions, and convergence of flow pathways with depth in these systems through biopores, structural interfaces, fissures and fractures. Likewise, recharge through soils to near-surface ground water aquifers is poorly understood, in part because water balance models are only approximate or undeveloped for areas of caliche occurrence. The hydrology of these soils on a site-specific basis has not been researched comprehensively, even though such knowledge is prerequisite to understanding water balance and wastewater loading rates in caliche soils. It is probable that such information will need to be gained if these soils are to be used for on-site treatment systems in regions of high environmental sensitivity, such as in limestone bedrock regions, near urbanizing communities, and wherever aquifers are subject to contamination from vadose zone inputs. This is particularly acute in the contributing zones to the Edwards aquifer along the Balcones Escarpment of Central Texas, but also germane to other regions of the State where urbanization has placed stress on establishment of central sewer systems to dispose of on-site wastes.

A case study of caliche hydrology in the Central Hill Country of Texas was reported by Wilding and Woodruff (1996). This involved a 3-year monitoring study from 1993-1995 at multiple sites within 3 small subbasins of the Barton Creek Watershed near Austin, Texas. Hydrological parameters were ascertained using infiltrometer, piezometer, tensiometer, shallow access wells, soil morphology, microfabric porosity, and microwatershed responses. This work demonstrated that the riser/tread microforms were essentially independent hydrological units. Ephemeral multiple water tables were perched within and among marly strata that exhibit limited interconnectivity. Locally, the risers served as recharge zones and the treads as interflow or discharge zones within given microform couplets. The cascading processes of water flow through multiple steps would retard discharge of incident water to downslope positions. In these caliche landscapes no systematic upslope to downslope trend in hydrology is apparent. Compartmental distribution flow processes replace Hortonian hydrological concepts in these landscapes. Vadose-zone hydrology is complex, temporal and local in scale.

What Is Known in the Literature About Caliche Soils and Wastewater Treatment?

Of the 205 different combinations and search engines used within the traditional literature, there were a total of 3608 keyword citation matches (Table 2). The percentage of keyword combinations obtained from this search is given in Table 3. Over 90% of the citations dealt with pH keyword combinations with effluent, wastewater, sewage, septic systems, and filter fields. Most of these were specific to municipal wastewater systems, reclamation of acid mine drainage, and land farming of sewage wastes. Likewise, most of the wastewater keyword combinations with limestone, calcium carbonate, and calcareous (and those associated with calcium carbonate and carbonate coupled with effluent and sewage) were directed to municipal wastewater issues.

Aggregating all of the above results together accounted for nearly 98% of the keyword combinations. There were 71 citations (about 2%) that appeared initially to be of possible interest. Upon further scrutiny of the titles and abstracts, only 35 contained information of general interest to the search at hand, and only 3 dealt specifically with wastewater treatment in caliche soils, per se. Several citations were duplicated in the initial search; however, they were not double counted in number of applicable abstracts reported above.

Table 2. List of keyword combinations and the number of results for each search engines used.

Search Engine	**Keywords Searched**	**Results**
GeoRef	pH + Effluent	5
Agricola	Wastewater + pH	2
Agricola	pH + Effluent	9
Web of Science	Wastewater + pH	13
Web of Science	Carbonate + Effluent	1
Web of Science	pH + Sewage	2
Web of Science	pH + Effluent	1
First Search	Wastewater + Limestone	4
First Search	Wastewater + Caliche	2
First Search	Wastewater + Calcium Carbonate	2
First Search	Wastewater + Calcareous	2
First Search	Wastewater + pH	52
First Search	Calcium Carbonate + Sewage	4
First Search	Carbonate + Sewage	5

Table 2. List of keyword combinations and the number of results for each search engines used. (Continued)

Search Engine	**Keywords Searched**	**Results**
First Search	Carbonate + Effluent	1
First Search	pH + Sewage	14
First Search	pH + Effluent	23
CAB Abstracts	Wastewater + Calcareous	2
CAB Abstracts	Wastewater + pH	7
CAB Abstracts	Carbonate+ Effluent	1
CAB Abstracts	pH + Sewage	4
CAB Abstracts	pH + Effluent	31
Water Resources Abstracts	Wastewater + pH	19
Water Resources Abstracts	Carbonate + Effluent	3
Water Resources Abstracts	pH + Sewage	8
Water Resources Abstracts	pH + Effluent	23
Applied Sci. & Tech Abstracts	Wastewater + pH	11
Applied Sci. & Tech Abstracts	pH + Effluent	19
Compendex	Wastewater + Limestone	43
Compendex	Wastewater + Caliche	1
Compendex	Wastewater + Calcium Carbonate	36
Compendex	Wastewater + Calcareous	36
Compendex	Wastewater + pH	1427
Compendex	Caliche + Effluent	1
Compendex	Calcium Carbonate + Sewage	19
Compendex	Calcium Carbonate + Effluent	33
Compendex	Calcium Carbonate + Septic System	1
Compendex	Calcium Carbonate + Filter Field	5
Compendex	Carbonate + Sewage	43
Compendex	Carbonate + Effluent	93

Compendex	Carbonate + Septic Systems	1
Compendex	Carbonate + Filter Field	12
Compendex	pH + Sewage	620
Compendex	pH + Effluent	923
Compendex	pH + Septic Systems	8
Compendex	pH + Filter Field	30

Table 3. Percentage of the keyword combinations obtained from the search.

Keyword	Results	Percent (%)
pH + Effluent	1035	28.6
pH + Wastewater	1535	42.5
pH + Sewage	648	18.0
pH + Septic Systems	8	0.2
Total	3256	90.2

Table 3. Percentage of the keyword combinations obtained from the search. (Continued)

Keyword	Results	Percent (%)
Wastewater + Limestone	47	1.3
Wastewater + Caliche	3	<0.1
Wastewater + Calcium Carbonate	38	1.1
Wastewater + Calcareous	40	1.1
Total	128	3.5
Calcium Carbonate + Sewage	23	0.6
Calcium Carbonate + Effluent	34	0.9
Calcium Carbonate + Septic System	1	<0.1
Calcium Carbonate + Filter Field	5	0.1
Total	63	1.7
Carbonate + Sewage	48	1.3
Carbonate + Septic System	1	<0.1
Carbonate + Filter Field	12	0.3
Carbonate + Effluent	99	2.7
Total	160	4.4
Caliche + Effluent	1	<0.1
Total	3608	100.0

Many of the publications dealt with:

- the use of crushed limestone or calcareous gravels as a sealant/liner in organic wastewater storage facilities and wetlands;
- efficacy in using calcareous media to immobilize various heavy metals;
- effects of effluent waste pH and dissolved organic carbon on flocculation of suspended solids oxidation/reduction reactions;
- ability of calcareous soil systems to buffer soil pH;
- hydraulic and loading parameters that determine P mobility in calcareous soil systems;
- soil physical and chemical changes from applying wastewater and sewage sludge to calcareous soils;
- optimal pH range for bacterial populations in soil systems;
- treatment of animal and biowastes in land application systems;
- influence of limestone geology on dispersal of nitrates and microbial pathogens;

- denitrification of domestic wastewater prior to a soil absorption system;
- temperature logging to detect sewage-polluted suface water infiltrating into fractured limestone rock.

The most pertinent literature directly germane to the effectiveness of caliche soils as a bioremediation filter media was that done by Liljestrand and Parten (1993), Parten and Liljestrand (1995), and Wilding and Woodruff, Jr. (1993). This research was done with caliche soils proximal to Austin, TX. Levine et al (1980) also conducted some valuable research to define long-term soil chemical changes resulting from the application of wastewater to calcareous soils in California. It was not clear from this work whether the soils used in this study would meet the working definition of caliche soils stated later.

In studies by Liljestrand and Partren, under both field and laboratory conditions, caliche soils:

- were effective in removing P and heavy metals from domestic wastewaters,
- had high efficiencies for removal of total organic carbon from effluents (97%),
- had high oxidation rates with rapid decay of BOD materials over short transport distances,
- were well buffered in the alkaline pH range because of calcium carbonate,
- had nitrate concentrations in the soils significantly higher than background or control cases for column studies,
- had low nitrate levels under field study conditions either due to plant uptake, nitrification/denitrification processes, or immobilization in upper soil/limestone layers,
- demonstrated minimal transport of the of the septic effluent into lower soil layers because high evapo-transpiration rates, except during significant storm events, and
- indicated possible transport of fecal coliform in surface runoff and subsurface flow through macropore conduits such fissures and fractures in the soil/limestone.

As alluded to by above studies, caliche materials are highly diverse physically, chemically, biologically and hydrologically. Laboratory studies of these materials are often misleading because it is difficult to scale up results to field sites. In situ monitoring of filter field systems for there efficiency in bioremediation of wastewater is in order and strongly justified.

The work of Levine et al (1980) is particularly interesting in that it illustrates some of the important long-term (30 years) physical and chemical changes that could occur with caliche soils under high hydrological loading rates of wastewater. These are identified as follows:

- soil pH decreases because of calcium carbonate depletion with possible nitrification and acidity,
- increase in total dissolved salts,
- stable organic carbon levels,
- very little total N accumulation within the soil (less than 2% over a 30-yr period), probably due to denitrification,
- continued soil capability to adsorb P but only 30% of total applied P could be accounted for in the upper 3m of the soil (possibly due to transport of P to underlying groundwater aquifer),
- soil CEC and exchangeable Na, Mg, and K increased, and
- soil metals generally increased (slight evidence that Fe, Mn, Ni, Co, Bo and Zn slightly mobile in upper soil.

It is not clear whether these results are directly transferable to caliche soils of Texas but the relationships observed in this study are worth considering in terms of long-term effects of the bioremediation quality of caliche.

Many of the results of the above two studies could have been predicted by a comprehensive knowledge of caliche soil attributes Wilding and Woodruff (1993). General physicochemical and hydrological functions of caliche materials pertinent to on-site wastewater treatment are:

- Moderately high to high organic carbon contents

- High surface reactivity due to reactive clays and organic carbon
- Chemisorption of P, Fe, Mg, Zn, Co, Cu, Pb, Sr, etc
- Buffered soil reactions above pH of 7.5
- Increased soil strength due to carbonate cements
- Limited root growth and water movement into soil matrix, especially petrocalcic and para rocks

Petrocalcic horizons or other subsurface restrictive layers such as lithic or paralithic bedrock contacts, restrict the biologically active soil zone for on-site remediation to the thickness of overlying horizons. Hence, the ability to identify a petrocalcic horizon and other probable restrictive layers is critical to knowledge about how a soil will function for on-site waste management, especially loading rates and residence times for remediation.

Petrocalcic horizons (or weakly fractured, carbonate plugged, subjacent hard limestones) function as aquitards (water restrictive layers) and may induce short-term reducing environments and increase the mean residence times of effluents for remediation. This would enhance anaerobic denitrification of NO_3, thus decreasing environmental hazards of NO_3 transport from the waste effluents to aquifers. However, it would negatively impact the site if it were overloaded with wastes and the effluents surfaced either on-site or off-site. For safe and effective utilization of caliche materials for on-site waste disposal, a functional knowledge of the local and regional hydrology is prerequisite. Research on this topic is of high priority because Texas has over 17 million acres (over 10% of the State) of caliche soils. In these soils water balance, hydrology, and pathways of water movement are poorly understood (Woodruff, et al., 1992; Wilding and Woodruff, 1993).

In summary, a soils knowledge of caliche is germane to on-site wastewater treatment in the follow ways:

- Soils are highly variable in soil depth, slope, drainage, and porosity and thus require on-site investigation for evaluation.
- Plant cover is restricted by arid/subarid climates, limited soil water retention, and deficient plant nutrients.
- Plant nutrient deficiencies in P, N, and trace elements are due to chemisorption of these nutrients to carbonate minerals.
- Low phytocycling of trace elements by plants would be expected because of high soil pH
- Rapid infiltration and drainage in many caliche soils occurs because of high gravel content and abundant macropores.
- Low water retention of gravelly caliche will limit loading rates.
- Most upland caliche soils are well aerated and drained favoring oxidation of organic compounds in A and B horizons, but may exhibit periodic reducing conditions at the contact with less permeable soil or bedrock substrata.
- Major hazard in wastewater treatment in caliche soils is NO_3 loss to shallow aquifers.
- Petrocalcic horizons or carbonate-plugged rock substrata function to:
    - limit soil depths and consequent load rates of wastes,
    - limit soil drainage and recharge into aquifers,
    - retard water flow above petrocalcic or joint-plugged bedrock yielding perched water tables,
    - enhance reducing conditions, and
    - restrict losses of NO_3 into aquifers.

What are Future Research Needs?

Based on above knowledge of caliche materials gleaned from the literature and from research activities of the authors, the following areas represent critical future research needs if caliche materials are going to be broadly utilized in Texas as filter media for on-site wastewater treatment:

- in-situ research on caliche materials conducted under field conditions rather than with laboratory column studies--the former cannot be adequately simulated in the laboratory because of changes in environmental and physical condition of packed columns compounded by scaling limitations that do not adequately represent spatial diversity of caliche soils in the field, even over a few tenths of an acre;
- establish specific pathways (soil structure, fissures, fractures, biovoids, etc.) of water transport in different types of caliche soils using anionic dye-staining techniques to assess risks for rapid discharge of wastewater into shallow ground water aquifers--use backhoe exposures to couple pathways of dye tracers with plant root distribution patterns, pedogenic carbonate translocation, and biological activity;
- document on-site hydrology of representative caliche soils to verify infiltration rates, depths and durations of saturation/reduction, presence of restrictive aquitards, water retention capacities, surface and subsurface discharge, and water balance models;
- establish risk assessments of nitrate, phosphorous, heavy metal and pathogen transport to subsurface aquifers when caliche soils are subjected to high rates of wastewater loading;
- develop models for calculating loading rates specific to caliche soil attributes; and
- determine hydraulic changes in caliche soils subjected to high loading rates of domestic wastes, especially evidence for dissolution of carbonates, formation of macroporosity, increased saturated hydraulic conductivity, and greater channel flow.

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Figure 1. Areas where calcic soils may be present in the southwestern United States, as interpreted from the soils maps of the United States (U.S. Soil Conservation Service, 1970). Areas of discontinuous or poorly preserved calcic soils are designated marginal. (Taken from Machette, 1985).

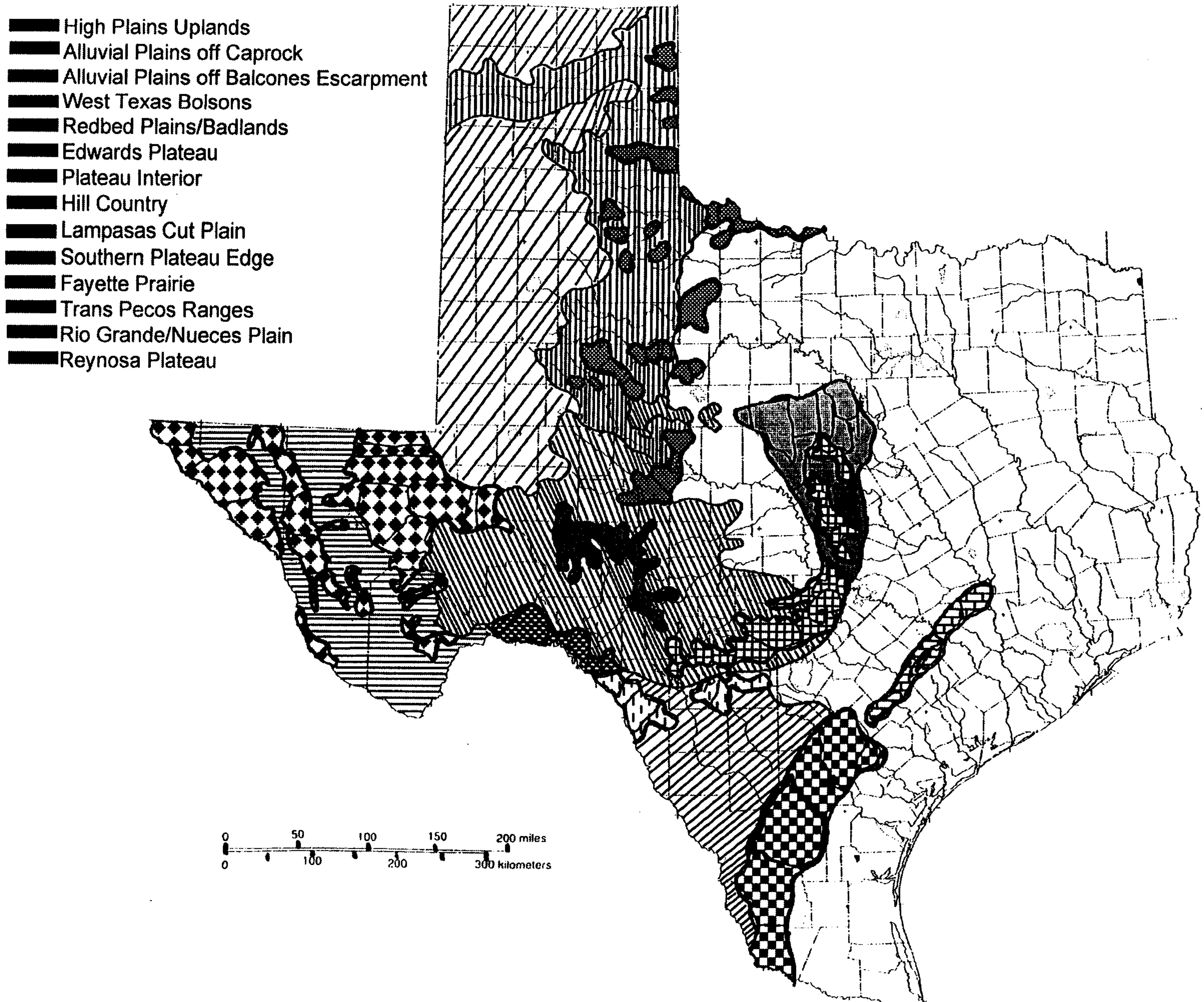
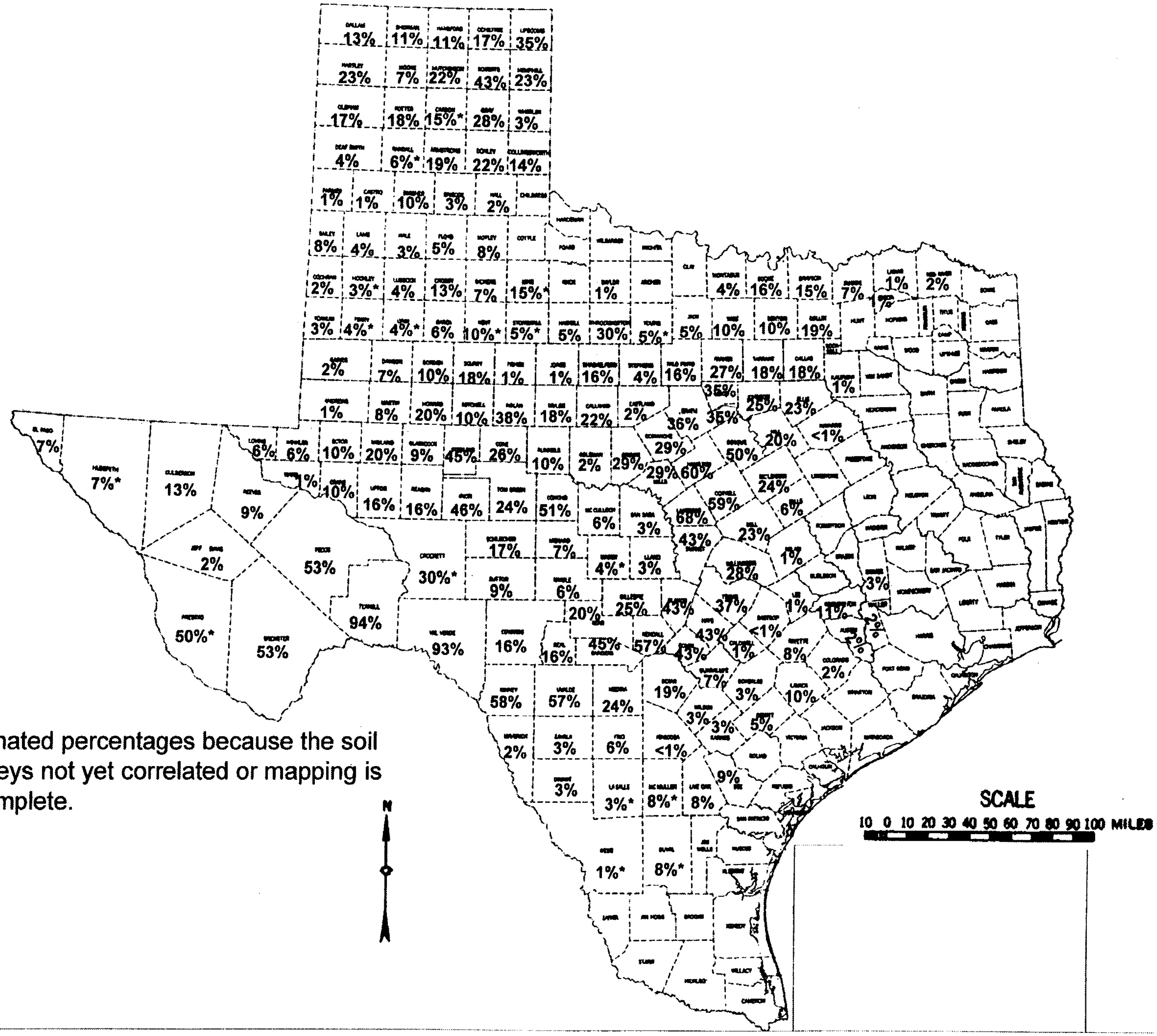


Figure 2. A generalized map illustrating bedbock/geologic regions of Texas having potential for claiche soils. (Modified from Bureau of Economic Geology 1992 and Ferguson, 1986).



* Estimated percentages because the soil surveys not yet correlated or mapping is incomplete.

Figure 3. Percentage of counties with caliche soils (Carbonatic mineralogy) according to Texas soil survey data. (Data courtesy of WayneGrabriel, Soil Scientist, USDA-NRCS, Temple, TX.)